ASEE 2022 ANNUAL CONFERENCE
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MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE

Paper ID #36690

Fifteen-Plus Years of Strength of Materials with Pool Noodles and More!

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Fifteen-Plus Years of Strength of Materials with Pool Noodles and More! (Best in 5)

Abstract

Over the years it has been widely recognized within the academic community, and published in the literature, that using physical demonstrations in the classroom helps students better visualize and understand behaviors and concepts being taught in lecture and coursework. Many different types of classroom demonstrations for undergraduate strength of materials courses involving the use of a variety of materials and experimental set-ups have been described by various authors. For many instructors the available time for preparing and using these demonstrations in class, as well as associated costs, can present challenges to utilizing this educational tool. This paper describes several strength of materials demonstrations used in the civil engineering technology program at Rochester Institute of Technology for beam bending, torsion, and column buckling involving no more than one or two pool noodles, a roll of masking tape, and a black magic marker, hence minimizing the time and cost factors. In addition, simple demonstrations for longitudinal shear in transversely loaded beams and stress/strain transformation are presented. Student feedback on the effectiveness of these classroom demonstrations for helping them visualize and understand specific physical behaviors is also presented.

Introduction

An important factor affecting student comprehension of key concepts taught in the classroom of undergraduate engineering courses is their ability to visualize the physical behavior related to those concepts. Numerous authors and researchers have documented the need and benefits of engaging students beyond the "traditional" lecture approach to improve learning in the classroom. Lowman [1] in Mastering the Techniques of Teaching states: "Listening and thinking activities are the primary activities by which students learn during class, yet students learn most from what they see." Similarly, Freeman and Walsh [2] identify engaging multiple intelligences, including spatial intelligence, as one of "ten brain-based strategies for college teaching and learning success." The importance of physical demonstrations for teaching the behavior of materials was emphasized in several National Educators' Workshops held in the 1990's and early 2000's, which were sponsored in part by the National Aeronautics and Space Administration (NASA).

Over the years instructors who teach strength of materials classes (mechanics of materials, solid mechanics) have used various types of simple classroom demonstrations and active learning exercises to help students visualize the physical behavior of materials and structural members related to key concepts in the course. As will be explained later in this paper, these demonstrations and active learning exercises have utilized different types of readily available materials and, in some cases, a fabricated ancillary device or frame. As discussed by Panther et al. [3], concerns that arise for instructors when trying to develop and implement new course materials in a class are the time and money needed to develop that material and the classroom time needed to effectively introduce and use it.

This paper describes physical demonstrations the author has used for the last 15-plus years in a second-year undergraduate strength of materials course at Rochester Institute of Technology (RIT) to help civil engineering technology students visualize material and structural member behavior. Most of them make use of nothing more than one or two pool noodles, a roll of masking tape, and a black magic marker. Using these items, effective demonstrations illustrating the physical behaviors associated with beam bending, torsion, and column buckling can be performed. Little time and money is needed for the instructor to create them and little class time is needed to effectively incorporate them into the lecture, thereby making them feasible for any instructor to use. Demonstrations related to the development of longitudinal shear in transversely-loaded beams and stress transformation are also presented and discussed. Student feedback from recent surveys regarding the effectiveness of the demonstrations has been obtained and is presented. However, since their implementation occurred gradually over the last 15 years, no specific evaluation of their impact on student grades and course ratings is possible.

Previous Studies

There are numerous papers in the literature describing different classroom demonstrations and active learning exercises used in strength of materials to help students visualize and understand the physical behavior of materials and structural members under loading. Table 1 provides a list of some of them along with the different materials used for each one. As seen from the table, a wide variety of readily available materials have been used. Some of the demonstrations listed in the table can also be found at the website "Hands-On Mechanics" [18].

Overall, the demonstrations/activities in Table 1 seem to have a positive impact on students' impressions of strength of materials courses and their performance, although there is some variation in the degree of that impact. Klosky and Vander Schaaf [11] and Lanning and Roberts [14] both reported significant improvements in student ratings of the course and instructor in semesters where demonstrations were used compared to previous semesters when they were not. In several studies [7], [9], [10], [13], [17] student ratings of the effectiveness of demonstrations or activities were generally on the positive side (as opposed to the negative side) of neutral, with ratings of generally 3.5 to 4 (4.5 to 5 in one study) on a 5-point Likert scale where 3 is neutral, 4 is agree and 5 is strongly agree that they were effective. Two studies [7], [8] also looked at changes in student performance on quizzes and exams when demonstrations were used in class compared to when they were not. Linsey et al. [7] found a greater improvement between student performance on pre- and post-topic quizzes for an experimental group that used active learning demonstrations compared to a control group that did not. On the other hand, Petersen and Davis [8] did not see an improvement in student learning between an experimental group that used them and a control group that did not. However, Petersen and Davis [8] identified some outside factors that may have contributed to this outcome including the fact the overall academic standing of the students who entered the strength of materials course was lower for the experimental group than the control group. Positive written comments from students about the use of lecture demonstrations and related activities were reported by several of the researchers listed in Table 1.

Table 1 – Summary of Demonstrations for Strength of Materials

Type of Demonstration/Activity	Material Used [References]
Axial deformation and stresses	• Rubber bands [4] or bungee cords [5] • Rectangular foam beam with grid markings [6] • Pipe insulation (foam) with square marking [7] • Surgical glove material with square and diamond markings [8] • Foam pool noodle [9] • Licorice [5], [10]
Shear loading (single or double shear)	• Pinned connections made from wood [4] • Spaghetti in acrylic plastic shearing device [11] • Glued craft sticks [9] • Hole punch in paper [12]
Bending deformation and stresses in beams	• Rectangular foam beam with grid markings [5], [6], [13], [14] • Pipe insulation (foam) with square marking [7] • Polycarbonate plastic beam and polarized lenses [7] • Coffee stir sticks [14] • Thin, rectangular strips of wood, dense cardboard, plastic or metal [12] • Block of cheese [15]
Deflection of beam (simply-supported and cantilevered)	• Rectangular plastic bars [9]
Poisson's ratio	• Marshmallows [10] or silly putty [13]
Centroids	• Angle iron [4] • 3-D printed body [16]
Moment of inertia	• Rectangular foam beam [6] • Yardstick [6] or coffee stir sticks [14]
Longitudinal shear in beam due to transverse loading	• Glued and unglued wood lathing [6], popsicle sticks [13] or coffee stir sticks [14] • Index card strips that are stacked but not bonded, then stapled or glued [12] • Thin plastic or metal strips [5], [12]
Combined loading and stresses	• Foam member (circular cross-section) with grid or square markings [6], [7] • PVC archery bow [17]

Table 1 continued on next page

Table 1 – Summary of Demonstrations for Strength of Materials (continued)

Type of Demonstration/Activity	Material Used [References]
Torsion loading and deformations	• Circular foam member - pool noodle/pipe insulation with grid or square markings [4], [6], [7], [12], [13] • Styrofoam tube with square/diamond markings [8] • Licorice [10] • Small diameter plastic rod/tube or wooden dowel [12], rubber rod [5], or PVC pipe [17] • Cardboard tube [12]
Torsion failure	• Chalk or Tootsie rolls [4], [7] • Pretzels or Licorice [9]
Stress transformation	• Rectangular foam beam with square markings [6] • Thin rubber sheet/glove [5], [8] or thick book [5], [11] with square and diamond markings
3-D stresses	• Plywood [4] or foam [13] cube with arrows on sides
Pressure vessels	• Portable air tank with pressure gauge [4] • Balloons with square markings [5], [6] • Hot dogs [5] • Wooden or plastic model [5]
Column buckling including length, end and/or bracing effects	• Rectangular foam beam [6], [13] • Acrylic sheet in wooden loading frame [11] • Steel ruler or wooden yardstick [9], [12] • Licorice [10] • Coffee stir sticks [14] • Small diameter wooden dowel [12] or PVC pipe [17]

In general, the use of lecture demonstrations or demonstration-based activities seem to have a positive impact on student impressions of strength of materials courses and student learning. New avenues for creating and using them continue to be explored including the use of 3-D printing [19] and mixed reality [20]. However, as previously discussed, some factors impacting whether or not an instructor adopts in-class demonstrations, or other new teaching strategies, are the time and cost required to develop them and the class time needed to effectively use them. In the case of strength of materials, many effective demonstrations can be done using no more than one or two pool noodles, a roll of masking tape, and a black magic marker, thereby eliminating the time and cost hurdle for the most part. These "pool-noodle-based" demonstrations, which the author has used for the strength of materials course at RIT over roughly the last 15 years, are explained in the next section of this paper followed by descriptions of two additional demonstrations and then presentation of student perceptions of their usefulness.

Demonstrations Using Pool Noodles

The author has used pool-noodle-based demonstrations in the lectures of a strength of materials course at RIT to help second-year civil engineering technology students visualize and understand the following concepts:

- beam bending and the resulting deformations and stresses,
- torsion in circular shafts and the resulting angular deformations and shear stresses, and
- column buckling.

In the sections that follow, details are provided about the pool noodle demonstrations used to illustrate each of these concepts. When the demonstration ties directly to a graphical figure used as part of a theoretical formula derivation, the parallel between it and the figure is highlighted.

Beam Bending and Moment of Inertia

Key concepts tied to the deformations and normal stresses caused in a beam by bending moment are readily illustrated by the graphical figures of a beam and beam element shown in Figure 1 and pool noodle demonstration shown in Figure 2. The behavior of the single pool noodle in the

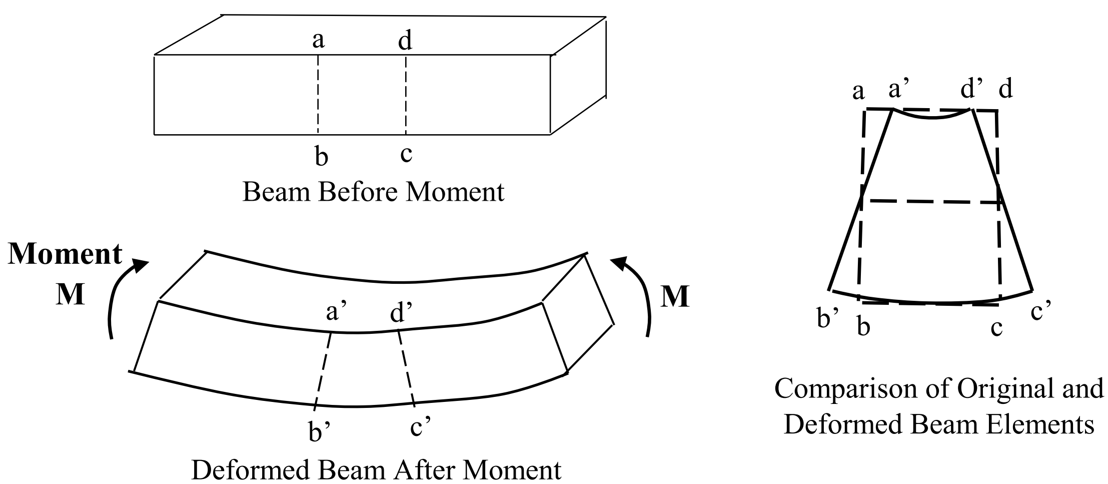


Figure 1 – Deformation of Beam from Bending Moment

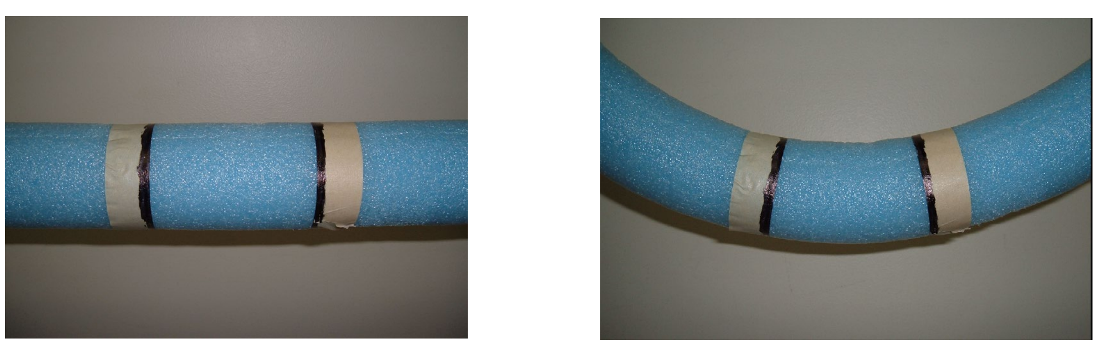


Figure 2 – Pool Noodle Demonstration Illustrating Beam Bending

demonstration directly mirrors the behavior illustrated in the graphical figure. The students can clearly see the upper edge of the noodle (beam) is in compression, the lower edge is in tension, and there is a linear variation in the deformation from one edge to the other. Since the beam element shown in Figure 1 serves as a basis for deriving the theoretical formula for normal stress resulting from bending moment (for loading within the linear elastic range of a material), the pool noodle demonstration reinforces this concept. It also helps to reinforce the concept that "plane sections remain plane" in a beam subjected to bending.

Tied to bending deformations and stresses in a beam is the concept of moment of inertia of the beam cross-section. The moment of inertia and its impact on beam deformations is illustrated by taping two pool noodles together at three locations to form a "beam" and applying load to it, as shown in Figure 3. By hanging a weight at the center of the horizontal beam with the cross-section oriented two different ways, students can clearly see the impact of moment of inertia on the deflection. They can also see the moment of inertia is tied to how the beam material is distributed relative to the axis of bending (centroidal axis) for the cross section.

Circular Shaft Subjected to Torsion

When a circular shaft fixed at one end is subjected to torsion due to an applied torque, it is important for students to understand the angular rotation of the shaft that occurs and how that rotation is related to the shear strain and angle of twist that develop. The graphical sketch shown in Figure 4 is often used to illustrate the rotation and its relationship to shear strain and angle of twist, which can then be related to each other using a formula given in the figure. The pool noodle demonstration shown in Figure 5, where the noodle is twisted around its longitudinal

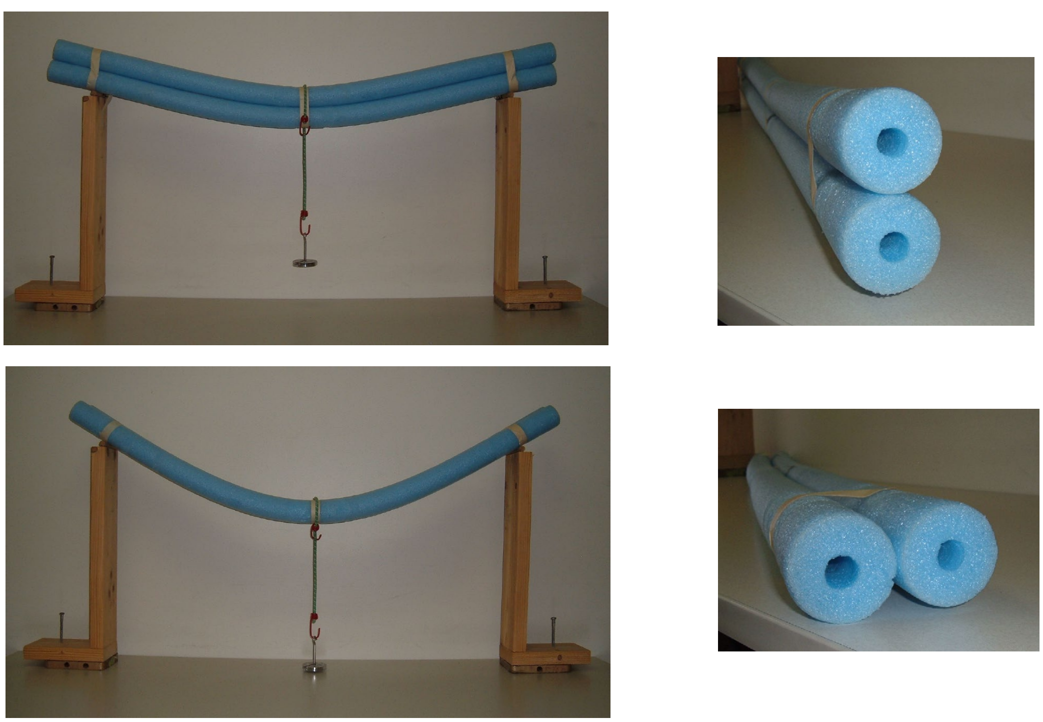
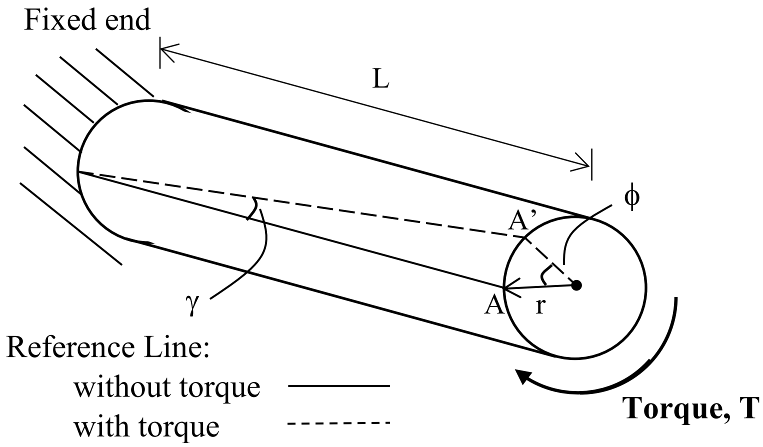


Figure 3 – Effect of Beam Moment of Inertia on Bending Deformations



For small angles in radians:

$$\text{Shear strain, } \gamma \approx \frac{AA'}{L}$$

$$\text{Angle of twist, } \phi \approx \frac{AA'}{r}$$

$$\gamma = \frac{\phi\, r}{L}$$

Figure 4 – Deformation of Shaft due to Torque

Without Torque

With Torque

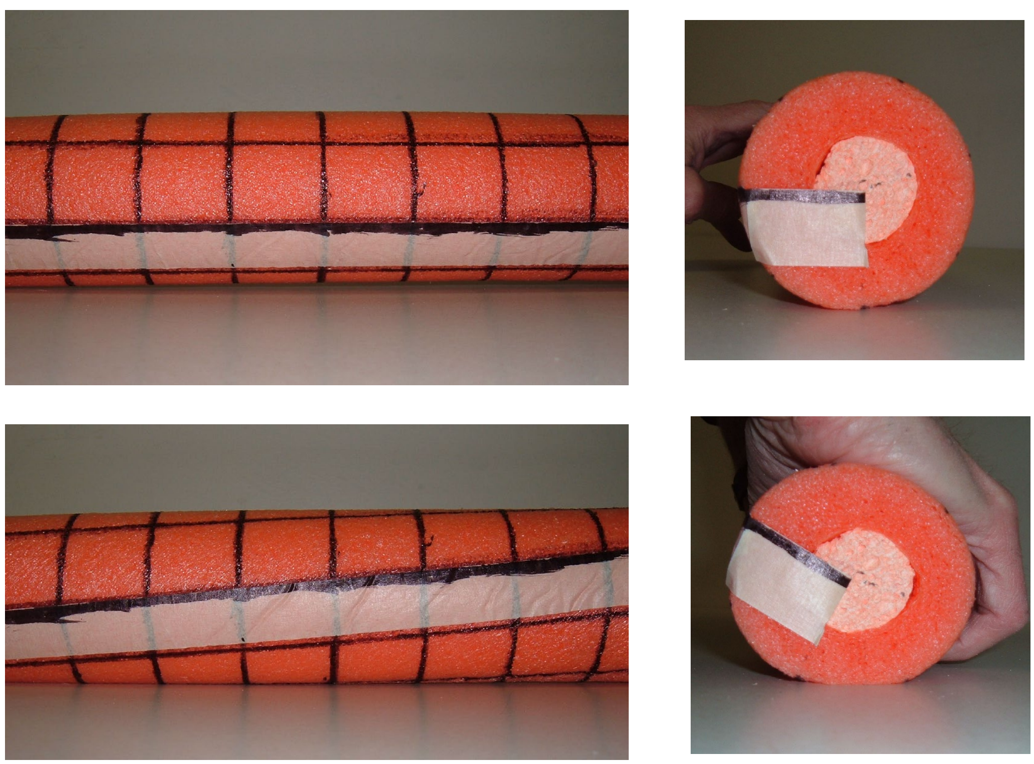


Figure 5 – Torsion Demonstration with Pool Noodle

axis using a pair of hands, ties directly to what is shown in Figure 4. The movement of the longitudinal taped line on the surface of the noodle allows students to clearly see the rotation that defines the shear strain at the surface. From the rotation of a radial line at the end of the pool noodle students can clearly see the angle of twist at the end, which should also help them deduce the shear strain in the circular shaft varies linearly from the center to the edge of the shaft. This observation can then be related to the shear stress in the circular shaft varying linearly from the center to the edge when the shaft is loaded within the linear elastic range of the material.

The pool noodle in Figure 5 also has a square grid drawn on the outside. When the noodle is subjected to torque, it is easy for students to see the shear deformation occurring in the square elements of material. Students can easily relate this observable behavior in the pool noodle to sketches in textbooks showing the same type of shear deformation. Although it is more time intensive to include these grid lines on the noodle model, they are helpful for visualizing the shear deformation that occurs.

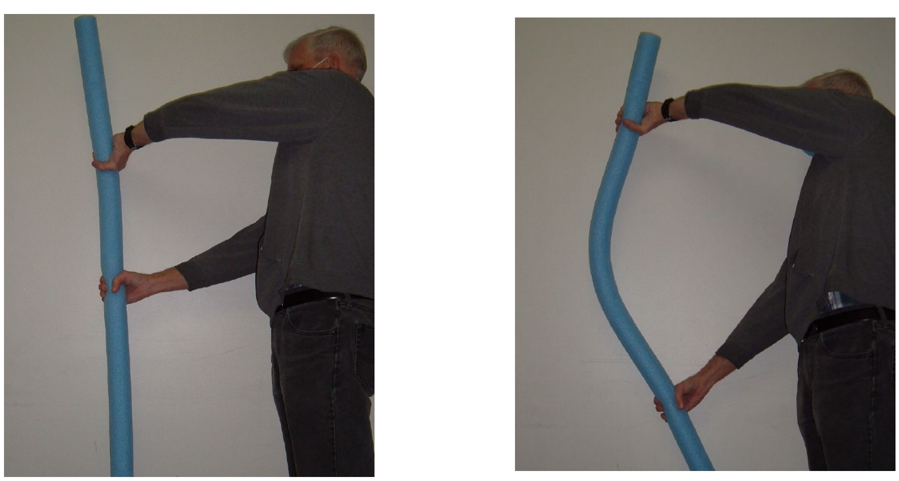
Column Buckling

There are several concepts directly related to the buckling of columns under axial compressive loads that students need to understand. These concepts include the physical phenomena of buckling itself and the following related factors affecting buckling:

- column length and its impact on whether buckling or yield of the column material will occur,
- end restraint condition of the column (i.e. pinned-pinned, fixed-fixed, pinned-fixed, or some other combination) and its effects on the deformed column shape and axial force causing buckling (buckling load),
- column cross-section and moment of inertia and its impact on the buckling direction and buckling load, and
- intermediate support bracing provided in the weak (buckling) direction of a column and its effect on buckling direction and load.

Each of these concepts and impacts are readily demonstrated using either a single pool noodle or two of them taped together.

The impact of column length on whether buckling or material yield of the column occurs is shown by firmly grasping a pool noodle with two hands spaced close to each other and pushing the ends closer together and then repeating the process with the two hands spaced farther apart, as shown in Figures 6a and 6b. In the former case the pool noodle will not buckle and it



(a) Short column "yield" behavior (b) Long column "buckling" behavior

Figure 6 – Column Length Effects on Buckling Behavior

simulates a “short” column under compressive load where yield of the material wants to occur. In the latter case the pool noodle buckles simulating a “long” column that buckles.

The effect of different end conditions of a column on the buckling load and shape can be demonstrated by altering the way the ends of a single pool noodle are held in the hands. As shown in Figures 7a and 7b, a pinned end can be simulated by resting the end of the pool noodle against the palm of a fully-opened hand and a fixed condition simulated by firmly grasping the end in the hand with all four fingers and thumb wrapped around the noodle. Using these techniques different column end support combinations can be simulated, such as pinned-pinned and fixed-fixed, showing the different buckled shapes they produce and illustrating the effective length concept used when evaluating column buckling. In addition, these demonstrations allow observation of the relative difference in effort required to produce buckling for different end conditions.

To demonstrate the impact of the column cross-section (perpendicular to length) and its moment of inertia on buckling direction and buckling load magnitude, two pool noodles are taped together at three locations along their lengths, as shown in Figure 8. The “column” is then loaded in compression in a similar fashion to that shown in Figure 7a. The demonstration clearly shows the column buckles around the cross-section axis that gives the lower moment of inertia, i.e. – around the “weak” axis of the column. This set-up can also show it takes more effort to force the column to buckle around the “strong” axis (one giving larger moment of inertia for the cross-section) of the column, as opposed to the “weak” axis.

Lastly, the use of intermediate bracing to improve buckling resistance is illustrated by using a column formed from two pool noodles taped together and a support (could be a person’s extended hands and arms) placed on each side of the column and oriented in the weak direction for buckling, as shown in Figure 9 (sometimes can be done with a support on only one side).

(a) Pinned-Pinned Ends (b) Fixed-Fixed Ends

Figure 7 – Effect of Column End Conditions on Buckling

Figure 8 – Effect of Moment of Inertia on Buckling Direction

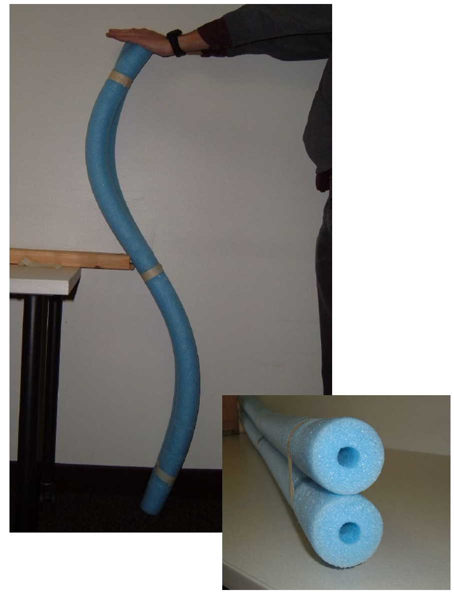


Figure 9 – Effect of Bracing on Buckling Length

Applying a downward load to the top of the braced column until it buckles shows the impact of the bracing on the buckling length for the column as well as the relative difference in effort to buckle the braced column in comparison to the unbraced column.

Other Demonstrations

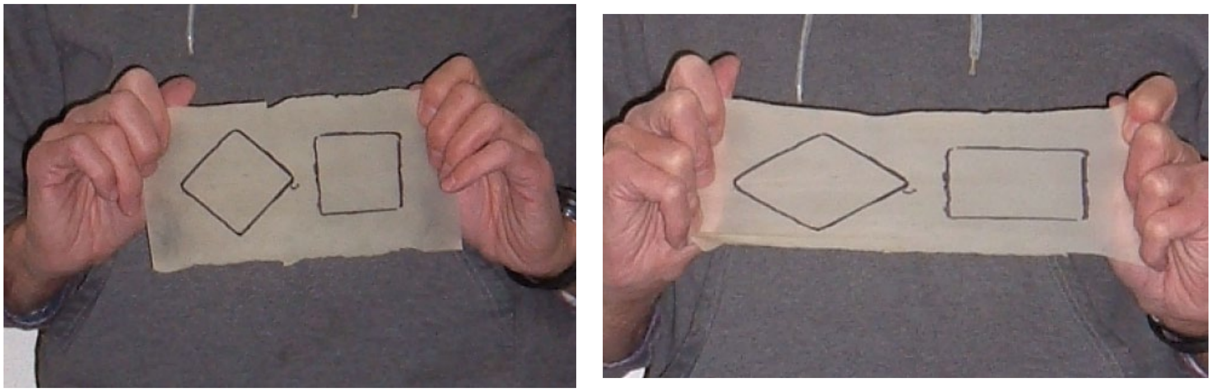
In addition to simple strength of materials demonstrations using pool noodles, the author has also made use of simple in-class demonstrations to illustrate two other important concepts including:

- stress and strain transformation in a loaded material and
- longitudinal shear in transversely loaded beams having fasteners.

Stress and Strain Transformation

The fact that normal and shear stresses and normal and shear strains observed in a loaded material vary with the reference directions (axes) for those stresses and strains is important for students to understand. Methods for evaluating the magnitude of those stresses and strains in different directions, such as stress and strain transformation equations or Mohr's circle, are readily available for students to learn and apply. But these evaluation methods do not allow students to physically see that the stresses and strains in a loaded material vary with direction.

The concept of stress and strain variation with direction is readily illustrated using a thin, rectangular rubber membrane, such as a triaxial test membrane for soils, having a minimum of two square blocks drawn on it oriented at different angles relative the sides of the membrane, as shown in Figure 10a. The sides of one block should be oriented so they are parallel to the sides of the membrane and the other block should be oriented at some other angle relative to the membrane sides. A tensile axial load is applied to the membrane by grabbing each end with a



(a) No Axial Loading (b) Axial Loading Applied

Figure 10 – Stress and Strain Transformation Demonstration

hand and pulling on the membrane in its length direction, as shown in Figure 10b. The block whose sides are parallel to the membrane sides clearly undergoes only normal strains whereas the other block undergoes shear strain, or both normal and shear strains, depending on its orientation. These strain observations can then be related to stresses.

Longitudinal Shear in a Transversely-Loaded Beam

In strength of materials, students learn about shear forces that develop on horizontal planes in a transversely-loaded beam due to variations in internal bending moment along the beam length caused by that loading. The shear force on a horizontal plane is often quantified per unit length of the beam using the shear flow, q, calculated using the formula:

$$q = V Q / I$$

where V is the internal vertical shear force at a particular location along the beam length, I is the moment of inertia of the beam cross-section (perpendicular to the length), and Q is the first moment of area (about the centroidal axis) of the cross-section segment isolated by the horizontal plane. Students learn when a beam is constructed from separate long pieces joined together using mechanical fasteners spaced along the its length, the shear flow along the horizontal planes where the pieces meet, and the resulting shear forces, must be resisted by the fasteners.

A simple demonstration for illustrating the development of shear along horizontal planes in a beam constructed using long pieces and mechanical fasteners has been developed and used by the author. The beam consists of two 23" x 3" x 2" rectangular blocks of packing foam (white polyethylene closed cell foam) and the mechanical fasteners are pretzels sticks and wooden dowels (approximately ¼-inch diameter), as shown in Figure 11. One beam is constructed using six pretzel sticks installed (in pre-made holes) completely through the upper foam block and into the lower block at a spacing of 3.75 inches along the beam length per the details shown in Figure 12. The assembled beam is then simply supported by placing a stand under each end, as shown in Figure 13, and downward vertical load is incrementally applied by adding weights to a hanger until shear failure of some pretzels occurs (snapping of pretzels heard). Horizontal slippage

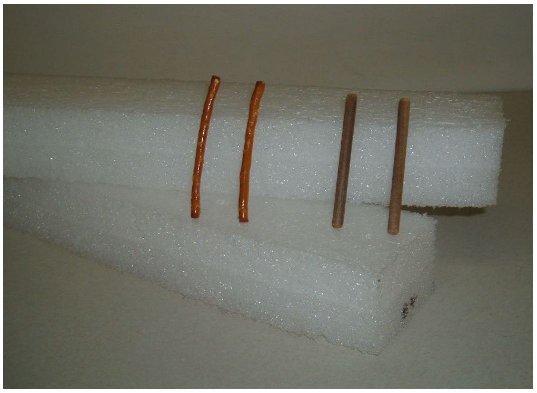


Figure 11 – Materials for Longitudinal Shear in Beam Demo

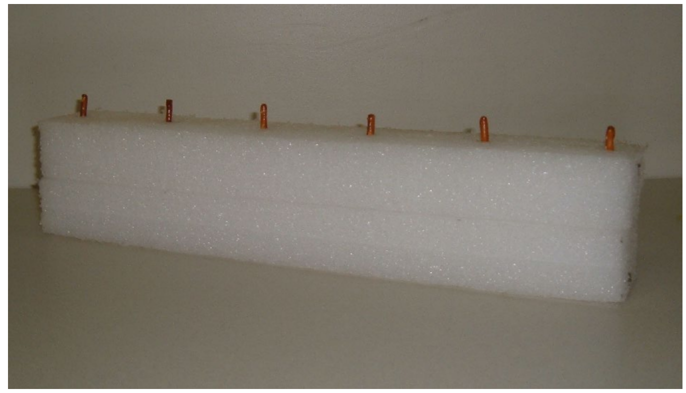


Figure 12 – Beam Constructed Using Pretzel Fasteners

(a) Before Shear Failure

(b) After Shear Failure

Figure 13 – Loading of Beam having Pretzel Fasteners

occurs in the failed beam and is evident from the offset seen between the ends of the upper and lower foam blocks (see detail in Figure 13b). The total weight applied to cause shear of the pretzels is recorded. The demonstration is then repeated two more times using beams of the same length but one having twelve pretzel fasteners and the other six wooden dowel fasteners. Results are compared to show the load capacity of the beam is dependent on the shear resistance provided by the fasteners used and the spacing of the fasteners.

Student Response to Demonstrations

Subjective, quantitative student feedback on the effectiveness and usefulness of the five demonstrations used in strength of materials lectures at RIT was obtained in Fall 2021 by having students complete surveys where they typically responded to six statements concerning each one. Possible responses to the statements, and the corresponding five-point Likert scale rating (given in parentheses) associated with each one, included strongly disagree (= 1), disagree (= 2), neutral (= 3), agree (= 4), or strongly agree (= 5). In addition, space was provided at the bottom of each survey where students could provide written comments regarding things they liked about each demonstration and things they disliked or thought could be improved.

Table 2 shows survey statements used to get feedback for the beam bending demonstrations, along with the response data from students. For each statement the number, and corresponding percentage, of students (out of the 15 total students in the class, all of whom completed the survey) who selected a particular Likert response is shown. In addition, the mean Likert scale rating obtained for each statement is provided in the last column. As seen from Table 2, statement 1 focuses on the demonstrations providing students the ability to visualize the development of tension and compression in a beam subjected to bending moment. Statements 2 and 4 respectively relate to them helping students understand the effects of beam cross-section and moment of inertia on beam bending and also helping the students understand the concepts being learned about the behavior of beams subjected to bending moment. Students' perceptions of the relatability of the demonstrations to the behavior of beams subjected to bending moment were obtained using statement 3. Lastly, statements 5 and 6 seek the students' opinions on whether the demonstrations were enjoyable and should continue to be used in future sections of

Table 2 – Survey Results for Beam Bending Demonstration

Survey Statement	**Number and Percentage of Students Selecting Likert Rating of 1 – 5***					**Mean Rating**
	1	**2**	**3**	**4**	**5**	
1. Bending moment demonstration with one pool noodle allowed me to visually see development of tension and compression.	0 0%	0 0%	0 0%	3 20.0%	12 80.0%	4.80
2. Loading of two-pool-noodle beam helped me better understand effect of cross-section and moment of inertia on beam bending.	0 0%	0 0%	1 6.7%	3 20.0%	11 73.3%	4.67
3. Demonstrations were clearly relatable to behavior of beam subjected to bending moment.	0 0%	0 0%	1 6.7%	1 6.7%	13 86.6%	4.80
4. Demonstrations helped me better understand concepts being learned about behavior of beams subjected to bending moment.	0 0%	1 6.7%	0 0%	5 33.3%	9 60.0%	4.47
5. I enjoyed the demonstrations.	0 0%	0 0%	1 6.7%	4 26.7%	10 66.6%	4.60
6. I recommend that these demonstrations continue to be used in this course.	0 0%	0 0%	1 6.7%	3 20.0%	11 73.3%	4.67

*Note: In rating system 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree.

the strength of materials course, thereby providing some additional insight into the students' feelings about their usefulness. Although not shown in Table 2, there was also a "contrary" statement at the end of this survey that said the demonstrations were not relevant to beam bending. This seventh statement was used to ensure students were not "blindly" filling out surveys. Such a "contrary" statement was also included at the end of the surveys for the other four demonstrations and in all cases the "strongly disagree" or "disagree" response given by all students indicated they did not blindly fill out surveys.

Survey statements used to get student feedback on the other four demonstrations used in the course were basically the same as those shown in Table 2. Due to the similarity of the student responses obtained for a particular survey question for all five demonstrations, mean ratings were calculated for each survey question using the responses from all five. These mean ratings are provided in Table 3, including the mean percentage of respondents who selected particular Likert responses to a statement (obtained by averaging the percentage of students who selected that response for all five demonstrations) and the overall mean Likert rating for that statement (obtained by averaging the mean Likert rating for that statement for all five). The range of the mean Likert ratings for a statement based on all five demonstrations is also provided. The number of respondents who completed a survey for each demonstration ranged from 12 to 15 students out of the 15 total students in the course. The total number of respondents completing surveys for all five demonstrations combined was 71.

Table 3 – Mean and Range of Responses to Survey Questions for All Five Demonstrations

Survey Statement	Mean Percentage of Students Selecting Likert Rating 1 – 5*					Mean Likert Rating	
	1	2	3	4	5	Overall Mean	Range
1. This demonstration allowed me to visually see the behavior being studied.	0	2.5	1.1	34.1	62.3	4.56	4.25 – 4.86
2. This demonstration helped me better understand a particular factor related to or affecting the behavior being studied.	0	1.8	5.4	30.2	62.6	4.54	4.33 – 4.67
3. Demonstration was clearly relatable to the concepts being learned about the behavior.	0	0	2.7	24.3	73.0	4.70	4.60 – 4.80
4. Demonstration helped me better understand the concepts being learned about the behavior.	0	1.3	5.4	36.3	57.0	4.46	4.33 – 4.64
5. I enjoyed the demonstration.	0	0	8.3	39.1	52.6	4.44	4.13 – 4.71
6. I recommend that this demonstration continue to be used in this course.	0	1.3	5.8	27.7	65.2	4.57	4.27 – 4.86

*Note: In rating system 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, 5 = strongly agree.

The overall mean Likert rating of 4.56 shown in Table 3 for statement 1, along with the fact 96 percent of the students agree or strongly agree with this statement, clearly indicate the demonstrations allowed students to visually see the material or structural member behavior being studied. Likewise, the mean ratings of 4.54 and 4.46 for statements 2 and 4, respectively, along with the fact 93 percent of students agree or strongly agree with these statements, confirms the demonstrations helped students to better understand a particular factor related to the behavior being studied, as well as helped the students better understand concepts being learned about that behavior. Students clearly felt the demonstrations were relatable to the material and structural member behaviors being studied as indicated by the mean rating of 4.70 for statement 3 and the 97 percent of students who strongly agreed or agreed with this statement.

The overwhelming positive reaction of the students to these demonstrations is further confirmed by their response to survey statements 5 and 6 where 93 percent of the students agreed or strongly agreed the demonstrations were enjoyable and should continue to be used when teaching strength of materials. This feedback, along with the responses to the other statements, supports the usefulness of this approach for helping students visualize and understand important material and structural member behaviors.

Forty-two written comments were provided by students on the surveys concerning things they liked about the five demonstrations used in lecture. Thirty-four of those forty-two comments were related to them helping the student see and visualize a particular material or structural member behavior and/or the effects of a particular factor on that behavior. Five students remarked the longitudinal shear in a beam with pretzel fasteners demonstration was fun, interesting, and interactive. Students also provided some written comments regarding how the demonstrations could be improved including using different types of objects/materials and improving the visibility of some of the markings on the materials used. One student noted the pool noodles used for beam bending were crude. Another student suggested trying to use a clear material for the beam parts in the longitudinal shear demonstration, rather than packing foam, so it would be possible to see what was happening to the fasteners inside the beam during loading to failure.

Summary and Conclusions

Over the years numerous faculty/instructors have implemented and reported on the use of simple in-class demonstrations for strength of materials courses to help improve student visualization of material and structural member behaviors, student understanding of concepts related to these behaviors, and performance in the course. The types of materials and set-ups used for these in-class demonstrations have varied from simple to more complex. In general, the response of students to them has been generally positive, particularly in comparison to course sections where they were not used. From an implementation and practicality standpoint, the ability to fabricate and use these types of demonstrations in class is greatly enhanced if they are simple and several of them can be performed using the same or similar materials, while at the same time maintaining their effectiveness.

This study has presented several different demonstrations that can be used in a strength of materials course and require no more than two pool noodles, a roll of masking tape, and a black magic marker. These demonstrations cover the behaviors associated with beam bending, torsion in a circular shaft, and column buckling. In addition, an effective demonstration for longitudinal shear in a transversely loaded beam having shear fasteners was discussed which uses two rectangular blocks of packing foam joined together with pretzel or wooden dowel fasteners. A stress and strain transformation demonstration was also presented involving no more than a thin rubber membrane with square block markings drawn on it at different orientations.

The demonstrations described in this paper have been used for 15-plus years in the strength of materials course for the civil engineering technology program at Rochester Institute of Technology. Survey feedback obtained from students in the course during Fall Semester 2021 clearly indicates the following:

- the demonstrations improve the students' ability to see and visualize the material or structural member behavior being discussed,
- they improve the students' understanding of factors related to a particular behavior, as well as concepts being learned regarding that behavior, and
- students enjoy their use in the classroom and overwhelmingly support their continued use in future offerings of the course.

Based on these results it appears important to continue using these simple visual demonstrations in strength of materials, as well as look for new ones that will further student understanding of key material and structural member behaviors.

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